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6. AUTHOR(S)
Dr. Kenneth Johnson
Dr. Kenneth Coale

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
San Jose State University Foundation
(Moss Landing Marine Labs)
P.O. Box 720130
San Jose CA 951720-0130

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13. ABSTRACT (*Maximum 200 words*)

The long-term goals of this work were to test the hypothesis that metals, especially iron, regulate rates of primary production in High Nutrient, Low Chlorophyll (HNLC) areas of the ocean. Two open ocean, iron enrichments were conducted in the eastern equatorial Pacific. Four nM iron was added in a single addition during the first experiment (Oct. 1993) and in three separate additions of 2, 1 and 1 nM in the second (May 1995). There was a strong response of the ecosystem with increases in primary production rates and plankton biomass. Large changes in bio-optical properties were also observed. The second experiment, in which higher iron concentrations were sustained for 1 week, produced a 20-fold increase in chlorophyll - a proxy for photoplankton biomass. The results of the experiments have been reported in some 20 journal articles.

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Kenneth S. Johnson & Kenneth H. Coale

METHOD DEVELOPMENT FOR AN UNENCLOSED IRON FERTILIZATION EXPERIMENT N00014-94-1-0125

Moss Landing Marine Laboratories
PO Box 450
Moss Landing, CA 95039
johnson@mlml.calstate.edu, coale@mlml.calstate.edu
408 755 8657 tel
408 753 2826 fax

The long-term goals of this work were to test the hypothesis that metals, especially iron, regulate rates of primary production in High Nutrient, Low Chlorophyll (HNLC) areas of the ocean. An important corollary of this hypothesis is that it might be feasible to regulate productivity in small patches in the open ocean by addition of small amounts of iron. The ability to produce "mini- blooms" would be an extremely valuable experimental tool for the study of ocean biogeochemistry, optical oceanography and remote sensing.

The primary objectives of the work were to perform the first mesoscale (64 km^2) iron enrichment experiments in the open ocean. The community response to these iron additions in HNLC waters was then determined. The first enrichment experiment was conducted in October/November, 1993 in the HNLC waters south of the Galapagos Islands at 90°W. The second was performed further west of the Islands (103°W). Iron (400 kg) was added with sulfur hexafluoride (an inert tracer) to 64 km^2 patches in both experiments. All of the iron was added in a single addition, bringing the mixed layer concentration to 4 nM in the first experiment. The iron was added in 3 separate additions over a 1 week duration in the second experiment to concentrations of 2, 1 and 1 nM.

The first iron enrichment experiment was a major success. Addition of iron to a 64 km^2 patch produced increases in chlorophyll concentration and primary production rates that were 3-fold elevated over background values (Martin et al., 1994). We were able to track this patch for 9 days before returning to port. These results demonstrate that iron does regulate biological rates in HNLC areas of the ocean. They also clearly indicate the feasibility of performing controlled experiments on open ocean ecosystems for significant periods of time. It is clear, however, that the ecosystem in the fertilized patch did not behave similarly to that observed in containers on board ship where all of the available nitrate is depleted when iron is added and chlorophyll may increase 30-fold or more. Three hypotheses might explain the lack of nitrate depletion observed in IronEx I: 1) another trace nutrient such as zinc was depleted, 2) grazing in the patch limited the growth of phytoplankton or 3) the iron was lost from the patch so rapidly that little was taken up by the phytoplankton and it rapidly became limiting again.

To test these hypotheses, iron was repeatedly added to the enriched patch during IronEx II in 1995. This patch was tracked over a distance of 1100 km during an 18 day span. Chlorophyll increased more than 20-fold during this experiment (Coale et al., 1996). At the same time, about one half of the available nitrate was consumed and the partial pressure of carbon dioxide was drawn down as much as 100 uatm (Cooper et al., 1996). Large amounts of

dimethyl sulfide were produced, as well (Turner et al., 1996). This result clearly eliminates the possibility that grazers or a second micronutrient limited the patch.

The results of the 1993 cruise have been summarized in 3 papers in Nature (Martin et al., Nature, 371, 123, 1994; Kolber et al., Nature, 371, 145, 1994; Watson et al.,371, 143, 1994). The results from all of the investigators in the 1993 cruise are in press at Deep-Sea Research II as a special issue of the journal.

The first results from the 1995 IronEx II cruise were published as 4 papers in Nature (Coale et al., Nature, 383,495-501, 1996; Behrenfeld et al., Nature, 383, 509, 1996; Cooper et al., Nature, 383, 511, 1996; Turner et al., Nature 383, 513, 1996). Several additional papers have been published by other investigators participating in the ONR funded expedition. This includes a paper by Kudela et al. (1996) on the optical properties of the iron enriched patch. Additional papers are in preparation including several from our group.

The two IronEx experiments have broad implications for how oceanography is performed. They demonstrate that we can move from an observational science into an era of controlled experimentation that will rapidly advance our understanding of chemistry, biology and optics. For example, deliberate experiments can now be conducted to assess the role of ecosystems in producing Colored Dissolved Organic Matter (CDOM) or biogenic aerosols such as DMS (e.g. Turner et al., 1996). The partitioning of natural isotopes in these experimental systems can be used to ground truth the processes that lead to biomarker formation and fractionation, such as alkenone temperature index.

The IronEx experiments have strong implications for the role of oceanic biology in regulating the climate of the earth. We are now working with NSF to plan a 3rd IronEx experiment in the Southern Ocean. Iron regulation of plankton growth in this region must be demonstrated if the iron-climate linkage is to be confirmed. In addition, we are working with the Monterey Bay Aquarium Research Institute to examine the potential for iron regulation of primary production and optics in the coastal zone.

Kenneth S. Johnson

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Moss Landing Marine Laboratories
PO Box 450
Moss Landing, CA 95039
johnson@mlml.calstate.edu
408 755 8657 tel
408 753 2826 fax

A. PAPERS From MLML ACKNOWLEDGING N00014-94-1-0125

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C. GRADUATE STUDENTS SUPPORTED

2 female - Ms. Heidi Zamzow, Ms. Laurie Ferioli
1 male - Mr. Peter von Langen

D. HONORS/AWARDS

K. S. Johnson, Sverdrup Lecturer, American Geophysical Union, 1994 - New technologies for ocean experimentation.